What Happens When Water Evaporates? An Inquiry Activity with Primary School Children

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Abstract. This paper is the result of a pedagogical intervention project carried out in a primary school. The intervention took place in a 4th grade class (n=24) and involved an inquiry-based approach to the teaching of the curricular topic “water phase changes”.

The project employed an action research methodology whose main goals were: a) to promote inquiry-based science teaching; b) to describe and analyse the process of the construction of meanings in relation to the phenomena under study, and c) to evaluate the learning acquired by the students. At the end of each lesson, a class diary was prepared - a descriptive and reflective narrative compiled from the field notes and audio recordings made during participant observation in the classroom. It was one of these class diaries that served as basis for this article, which describes and analyses the process of scientific meaning construction occurred in the classroom, around the phenomenon of "water evaporation".

The results of the assessment on the learning acquired show that the vast majority of students developed an atomistic model to explain the phenomenon of water evaporation, in which liquid water turns into small, invisible particles (water vapour), which become part of the air around us. This model is consistent with the notion of conservation of matter.

Keywords. Inquiry-based science teaching, water evaporation, elementary science.

1. Introduction

Very early on, children manifest a natural curiosity and interest in knowing and making sense of the world that surrounds them. The teaching of sciences should take advantage and enhance these natural qualities in children, as they constitute the necessary support for active and meaningful learning in the classroom [1, 2, 3]. The goal is to “educate” the children’s natural curiosity in order to develop more systematic, deeper and more autonomous thinking patterns [4]; stimulate them to pose questions and look for possible answers for what they do and see; enable them to devise ways to test their ideas and thought strategies; to share and discuss their own theories and explanations with others [5, 2]. Unfortunately, the traditional educational system works in a way that generally discourages the natural process of inquiry. Thus, the meaningful exploration of inquiry-based science activities stands as a privileged means to convert classrooms into places of leisure, satisfaction and personal fulfilment, as they allow the creation of a learning environment where children learn and do things they really enjoy [3, 6]. A stimulating and challenging learning environment, which can be provided by exploring inquiry activities, is essential for the children's social and intellectual development [7, 8, 9].

Inquiry-based science education in the early years of schooling is, therefore, vital to help the children: understand the world around them; learn to obtain and organise information; develop ways to discover; test ideas and use evidence; and develop positive attitudes towards science [2, 10]. On the other hand, it can also help children develop very different thinking skills early on [11], e.g., scientific thought, critical thinking, autonomous problem solving and meta-cognitive skills, which are likely to be transferred and applied to other contexts and learning situations [7, 8]. Finally, we could say that inquiry activities in science classes also offer a privileged setting for the use and development of other fields of knowledge, specifically oral and written language and mathematics [2, 3]. Science education is, therefore, of great importance for children, as it promotes the development of processes, concepts and basic attitudes that will be indispensable for subsequent scientific learning [2, 10].

The importance of science for children has been widely recognised in the science curriculum guidelines of many countries, which, like some international organisations, have also recommended inquiry methods for its approach. However, in the majority of European countries, the reality of classroom practice is that these methods are being implemented by relatively few teachers [12, 13].

2. The students' intuitive ideas and the understanding of water evaporation

A study conducted by Russell, Harlen and Watt [14], showed that children have intuitive conceptions about the evaporation of water, which can be grouped into three categories: a) there is no conservation of the quantity of water. Evaporated water simply ceases to exist; b) there is a change in location without transformation of the water; c) there is a change in the location of the water with transformation into in a visible or invisible form. It should be noted that atmospheric air is almost never referred to as the place where evaporated water goes.

Bar and Galili [15] state that the conceptual change of views regarding evaporation in children's minds shows a clear correlation with their cognitive development, namely the use of the conservation principle and the adoption of an abstract model for air. Children's conceptions of evaporation could be categorised into one of four age-related views, as follows: (1) the water disappears (age 5-6); (2) the water penetrates solid objects (7-8); (3) the water evaporates into some "container" (9-10); or, (4) the water evaporates, it is scattered in the air (age 10-11).

The understanding of the evaporation phenomenon by students requires the ability of abstraction: liquid water, which they can see and feel, turns into water vapour, a material body made up of tiny particles, which they cannot see or feel. According to Sá [3], there are four aspects to consider in the development of the concept of evaporation in children: a) the concept of conservation of matter, despite the transformation occurred: the water continues to exist despite no longer being visible; b) the change of location of the evaporated water. Where does the water go?; c) the conditions or factors that influence the evaporation rate; d) the nature of the transformation that the water undergoes during the evaporation process.

Often, when children approach the concept of evaporation, through the activity of observing the amount of water in a container decrease when in contact with air, their idea of evaporation is limited to the context in which the liquid has a surface in contact with air. Consequently they will be able to apply that notion to ponds, rivers and oceans, but they will be unable to explain the drying of clothes or the transformation of mud into hard, parched earth through evaporation. The drying of clothes and the evaporation of water from a cup are seen by children as different phenomena [3]. This means that the development of a concept or idea requires the diversification of activities, i.e. different science education contexts where the same phenomenon occurs [2].

3. Objectives

A pedagogical intervention project was developed, with the aim of promoting an inquiry-based science teaching practice in the approach to the curricular topic “water phase changes”. For that purpose, several lessons were planned and implemented in the classroom. Thus, the specific objectives of this paper are: a) to describe and analyse the teaching and learning process promoted in the classroom during the exploration of one of these lessons, and b) to assess the learning acquired by the children.

4. Methodology

The science teaching project adopted an action research methodology and was carried out with a class of the 4th year in a Portuguese primary school, located in the city of Famalicão.

The class was composed of 24 students, 13 boys and 11 girls, aged between 9 and 10 years. For two months, 5 lessons were taught on the curricular topic "Water phase changes”, amounting to a total of 10 hours of intervention in the classroom, as presented in the table 1.

For each topic addressed, a teaching and learning plan was prepared, containing the following elements: i) learning goals; ii) materials needed for the groups to carry out the planned activities; iii) guidelines for the teaching and learning process; and iv) an individual record sheet for each student.

Each lesson, which corresponds to one action research cycle, begins with a teaching and learning plan, which is implemented flexibly, according to the teaching and learning processes generated and promoted within the reality of the classroom. The lessons were taught by the second author of this paper, who, in collaboration with the class teacher, played the role of both researcher and teacher.

Lesson subject	Duration
Solid, liquid and gaseous materials: What are the differences?	2h 00m
Fusion and solidification of water	2h 00m
Water evaporation	2h 30m
Condensation	2h 00m
The water cycle	1h 30m
Total	10h 00m

Table 1. Lesson subject and duration

The data generated in this intervention was collected using two complementary methods: the field notes made by the researchers and the audio recordings of the lessons. This raw data was subsequently compiled in the form of detailed narratives that include the most relevant events that took place in the classroom – the class diaries. These constituted the main method of recording data and, simultaneously, a strategy for reflection and for the modelling of the teaching and learning process [16]. This paper aims at describing and analysing the teaching and learning process promoted in the classroom, based on the class diary about water evaporation.

With the purpose of assessing the learning acquired by the children, a questionnaire was prepared and administered three weeks after the pedagogical intervention.

5. Results

5.1. Class diary content analysis

In small collaborative groups, the students investigate water evaporation, in terms of the variation in the amount of water occurred after a few days in an uncovered cup, in a cup with wet earth and in a wet cloth. The lesson begins with the following question:

A. What will happen to the water in this cup if we leave it uncovered for a few days?

- A_1. The students make predictions.

Their answers suggest that the water will evaporate: "the water will evaporate" (Rodrigo); "it will evaporate" (Ana); "it will evaporate because it will be in the cup for many days" (Catarina). However, when asked if the amount of water in the uncovered cup will be the same after a few days, opinions are divided: some argue that yes, while others believe that the amount will be different.

- A_2. The students discuss the different predictions. Excerpt from the class diary:

"I think it will evaporate and no water will be left" (Ana). "The cup will have less water, because of the sun, which will turn the water into the gaseous state" (Rodrigo). "The water will evaporate because of the heat in the room" (António). "It will disappear, but very slowly, because of the sun and the temperature of the room" (Afonso).

After the collective reflection and discussion, it appears that: a) there are more and better arguments in favour of a reduction in the amount of water in the uncovered cup, due to the fact that it is subject to the phenomenon of evaporation; b) there are those who justify their opinion based on the water passing from the liquid to the gaseous state. The sun and the heat of the room are seen as the agents of this phase change; c) there are those who use the term "disappear", which could mean that the evaporated water ceases to exist - absence of the notion of conservation.

- A_3. The students record their predictions.

Most children (22; 91.6%) predict that the amount of water in the uncovered cup will be smaller after a few days. Only two children (2; 8.4%) wrote on their record sheet that the amount of water will remain the same.

B. How can we find out who is right? Planning a strategy to test the predictions.

- B_1. The students reflect and negotiate the best way to test their predictions.

"We can take the cup with water and draw a small line on it. Then, on Monday, we'll see if the water is still at that line" (João A.). Rodrigo suggests a different idea: "weighing the water; then, we would weigh it again and see if the weight was the same". When asked to give their opinion on these ideas, the class is unanimous in considering Rodrigo's idea the best. In an effort to preview the results, students state that the amount of water will decrease in terms of weight variation: "the water will lose weight because, as it evaporates, it will lose the weight of the water lost in those days" (João L.). Children who previously said the weight would remain the same are now unable to find a plausible explanation.

- B_2.The children build a rudimentary scale. Excerpt from the class diary:

"How can we measure the amount of water evaporated if we do not have a scale?" – I asked. In the absence of answers, I give them some tips to build a scale with two empty yoghurt cups, a small plastic rod and a piece of string. With my help, the groups build their scales and make a few comments: "The cup that goes up is the lighter one" (Rúben). "The heavier cup goes down" (Inês).

- B_3. The students plan out procedures to balance the scales:
    - After the construction.

"Now, how will we balance the scales?" – I ask. "The cups have to be in the same position" (Fábio). "The stick has to be straight" (Sérgio). Given their difficulties, I help the groups to balance their scales.

It is difficult to balance the scale when the two cups are suspended, because of the length differences that may exist in the strings that support them. The scales are balanced by positioning the plastic rod horizontally, through the following procedures: a) the students move the string tied at the middle of the plastic rod to the left or to the right; b) or they move the strings tied to each end of the plastic rod to the left or to the right, depending on the imbalance.

- After water is put into one of the cups.

"What should we do now to find out the amount of water that evaporated?" "We have to put water" (Luísa). "We put water in one of the cups and something else in the other cup, until the scale is straight". "What "other thing" will we put in the other cup?" – I ask. In the absence of any answers, I pick up a handful of beans and, immediately, Sérgio says: "We put in an amount of water and then we put beans in the other cup until the scale is straight (balanced)".

C. Now, what will happen to a wet cloth and a bit of moist earth?

- They apply the previous knowledge to the new contexts.

"It will dry out" (Ana). "The weight will decrease because the cloth will dry out and then it will no longer have as much water" (Mariana). "The water evaporates and then the cloth gets lighter" (Inês). "And what will happen after a few days, if we put this wet earth into a cup as well?" "The scale will be tilted because water has weight and, as it evaporates, it will get lighter" (João A.). "The water will evaporate and the cup with the earth will be lighter" (Luísa).

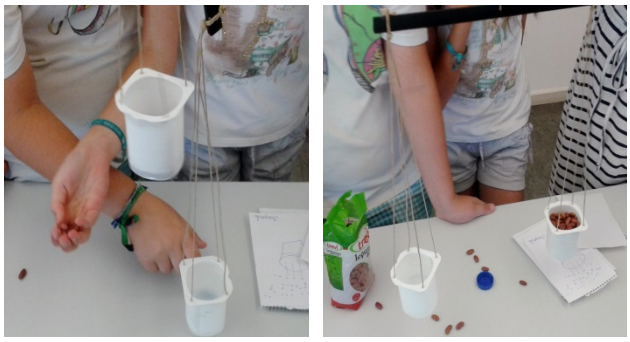

Figure 1. The groups balance their scales

It is relatively easy for students to mobilise and apply the previous knowledge to new contexts. Throughout this process, it should be noted that: i) the predictions about what will happen to the wet cloth and the wet earth, unlike what was previously found for the cup with water, are now converging towards the fact that the amount of water will decrease after a few days; ii) the variations in the amount of water that will occur in both contexts, due to the process of evaporation, are now referred to in terms of weight variation.

D. How can we find out if the amount of water will decrease in all three cases?

- The students perform the procedures.

With my help, each group performs one of the following balances of the scale: water/beans, wet earth/beans, damp cloth/beans. I interact with the groups and ask if the scale is balanced. "The cup with water still outweighs the other" (Inês), "What do you need to do?" – I ask. "Put in more beans" (Ana). "Put less water" (Maria). They remove some of the water from the cup and some of the elements of the group say: "It's not there yet"; "Now it's equal"

(Rúben); "now it's balanced" (several). With my help, the balanced scales are suspended from a rope in a corner of the classroom.

E. What differences do you see in the scales since the last lesson?

- The students interpret their observations.

On Monday morning, after three days, I ask: "What differences do you see in the scales?" "They are tilted" (António). "The water evaporated" (Margarida). "Why did that happen?" "Because the beans in the cups did not evaporate and then, as the water evaporated, they became heavier" (Ana). "The heavier cups are lower" (Rúben). "The water evaporated from all the cups" (Fábio). "In the cups with the cloth and the wet earth, water also evaporated and they got lighter" (Inês).

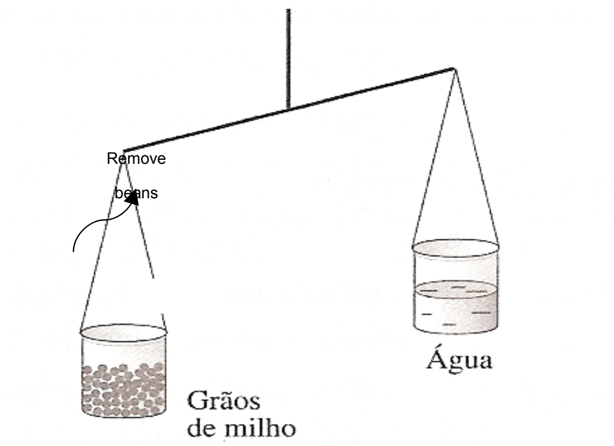

Figure 2. Procedure 1: water/beans.

F. How can we measure the amount of water that evaporated?

- F_1. The children suggest a procedure.

Students show that they understand that the amount of evaporated water can be obtained by re-balancing the scales. They suggest removing beans from the heavier cups (which are lower), until they obtain a new balance: "removing beans" (Rodrigo); "the beans that we remove are the weight" (Rúben); "that is the weight of the water that evaporated" (Margarida).

The figure 2 illustrates the procedure suggested by the students:

- F_2. They reflect on a possible unit of measure.

"Is it possible, then, to use the beans as a unit of measure?" – I ask. "Yes, the beans we remove are how much it weighs" (Rúben). "That is the weight of the water that evaporated" (Inês). One of the groups removes and counts beans from one of the scales, until it is balanced. "So, the water that evaporated corresponds to how many beans?" "Twenty-three" - they answer. "By removing the beans, the scale got straight" (Inês). "The beans are the weight of the water that evaporated" (Fábio). "By removing the beans, we learn the amount of water that evaporated in beans" (Nuno).

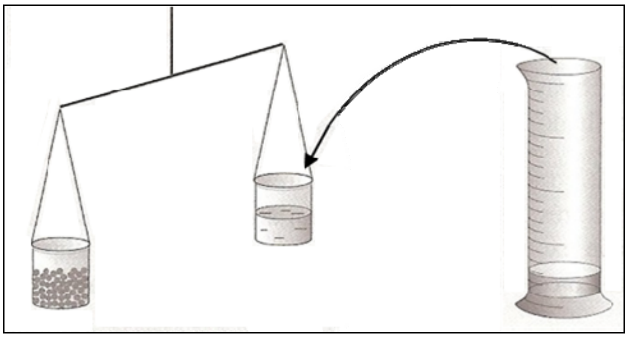

Figure 3. Procedure 2: water/beans

- F_3. They measure the water that evaporated in *ml*.

I encourage the students to think about another procedure to measure the amount of water that evaporated in the three situations (cup with water, cup with wet earth and cup with wet cloth). "Put in more water and measure" (Mara). "Measure the water that the cups have" (Tiago). "What will we use to measure?" – I ask. "We'll have to use a measuring cup" (Rúben). I give Rúben a beaker. I put 80 ml of water in the beaker. In the scale built by his group, and with the help of his classmates, he pours water until the scale is balanced. I ask to see how much water was left in the beaker. He replies that 68 ml were left. "What is the amount of water that evaporated?" "The amount evaporated was 12 ml. We calculate the difference" (Jorge). The groups perform the same procedure to measure the amount of water evaporated in the remaining situations and find out it is different: 8 ml in the cup with wet earth and 10 ml in the cup with the wet cloth.

- F_4. They record the data in a table.

By way of illustration, the following is the type of record made by the students in their record sheet.

Balanças	V. inicial	V. final	Água evaporada (ml)
A. Com água	80 ml	68 ml	12 ml
B. Com terra húmida	80 ml	72 ml	8 ml
C. Com pano molhado	80 ml	70 ml	10 ml

Figure 4. Example of a record sheet (in portuguese).

The results obtained are consistent with the predictions originally made by all the groups - water evaporation in the three contexts.

G. Where did the water that evaporated go?

- Collective reflection and discussion.

"It went to the sky" (Ana). "To the clouds" (João A.). "It went outside. The water went outside. Clouds can't form in here" (Mafalda). "When water evaporates, it goes up" (Nuno). "Does the water that evaporates go immediately up to form clouds?" – I ask. Tentatively, some say "no" and Nuno intervenes: "When we heat water on the stove, we see the water coming out and the extractor hood gets wet". "So where did the evaporated water go?" "It went into the air" (Jorge). "It spread throughout the air" (António). "Then what exists in the air?" "Water" - Inês promptly answers. "In what state is that water that evaporated?" – I ask. "In the gaseous state" (Rúben). "It must turn into tiny droplets, but we cannot see them" (Nuno). So what happens to water in things when they dry? "It goes into the air, all around us" (several students). "Water turns into "little things" that we cannot see, but that are there" (Rodrigo). "They stay in the air" (Margarida).

Figure 5. Example of a drawing made by one of the students

During the collective reflection and discussion, when students are asked where the evaporated water has gone, explanations of different conceptual levels arise:

a) One argues that the evaporated water - water vapour - goes directly to the clouds. This is an intuitive notion that, if accepted, does not even include a phase change, as in the clouds, water is in the liquid state.

b) Another expresses the idea that water vapour is now in the air, the students failing, however, to suggest a more explanatory theory.

c) Lastly, a third one reveals an atomistic concept of evaporated water, which is consistent with the concept of conservation. In this theory, evaporated water does not cease to exist, but merely undergoes a change in physical state, now taking the form of small, invisible particles: "water turns into "tiny things" that cannot be seen, but that are there". This notion is present in some of the drawings made by the students at the end of the lesson.

5.2. Assessment of learning

Three weeks after the lessons, the following question was included in an assessment test:

Mark the correct sentence with a cross (X):

a) The water in the cups disappeared and ceased to exist.

b) The water disappeared and went straight to the clouds.

c) The water is now in the air, in small particles that cannot be seen.

In the graph of figure 6 it is shown the relative and absolute frequency distribution of the student's answers.

It was found that a vast majority (71%) of students developed an atomistic model to explain the phenomenon of water evaporation, in which liquid water turns into small, invisible particles (water vapour), which move around and are carried by the air that exists all around us. This model is consistent with the concept of conservation of matter – only one child marked sentence (a) as correct.

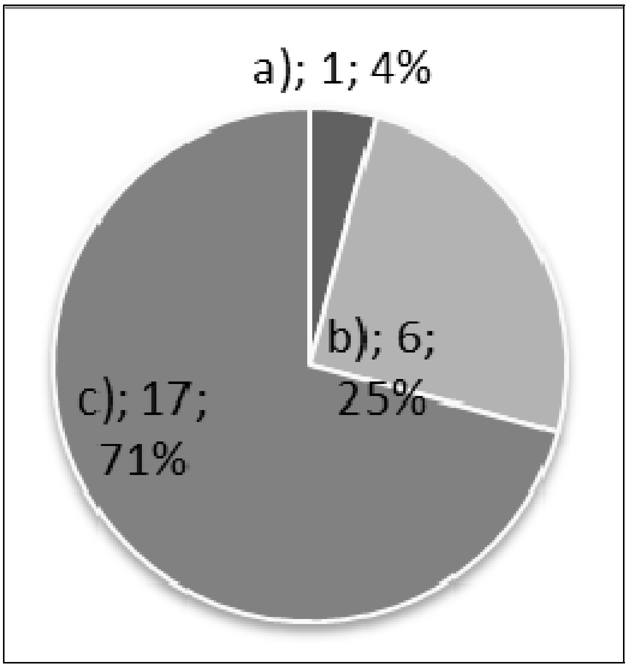

Figure 6. Students' answers

6. Final considerations

The data contained in the class diary takes on the nature of a sample of the learning acquired by the children, not allowing for any illations about the degree of individual learning achieved by each one. However, the combination of that learning with the data obtained on the items of the individual assessment question shows that most of the children in the class, in order to explain water evaporation, developed a model in which liquid water turns into small, invisible particles – water vapour –, which move around and are carried by the air around us. This model is consistent with the notion of conservation of matter.

According to Coll and Martín [17], an evaluation that is based on the consideration of an instant situation is unreliable, as it fails to take into account the dynamic nature of the meaning construction process, as well as its temporal dimension. In this regard, the results obtained in the items of the assessment question, three weeks after the lesson, also allow claiming that this learning was significant, as opposed to memorisation, which is quickly forgotten.

The teaching and learning process analysed above, on water evaporation, entails great personal and intellectual involvement by the children and is closely dependent on an intervention intentionally guided by the teacher, which aims at promoting in them both the construction of meanings that are more consistent with reality and the development of scientific process skills. In this sense, the teacher plays a key role. The teacher, through a process of questioning that stimulates the children's thoughts and actions [3], supports their individual and collective cognitive activity [18,19]. Through this process of questioning [19] guided by the teacher, students are able to reach higher levels of comprehension and, simultaneously, develop better thinking skills, which they would not be able to achieve without support.

Lastly, we would like to point out that the initial and in-service training of primary school teachers should be able to endow them not only with scientific knowledge, but also with specific didactic knowledge on how to explore the different curricular topics with the children. The development of this knowledge should be based on the data and tools that emerge from research undertaken with children in the classroom context. Research in science education should offer fruitful elements to support the educative action of the teachers. In this sense, the analysis presented in this article, about the activity "water evaporation" may constitute both a didactic resource for teacher training and an element of support for those teachers, so that, in similar contexts, they are able to promote the same teaching and learning process with their students.

7. References

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